RL-TR-97-169
Final Technical Report
October 1997

COSMOS - A SYSTEM FOR ACCUMULATING AND MANAGING DISTRIBUTED DESIGN KNOWLEDGE

Lockheed Martin Missiles & Space Advanced Technology Center

Sponsored by
Advanced Research Projects Agency
ARPA Order No. AO 8767

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

19980310 167

DTIC QUALITY INSPECTED 4

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the Advanced Research Projects Agency or the U.S. Government.

**Rome Laboratory
Air Force Materiel Command
Rome, New York**

This report has been reviewed by the Rome Laboratory Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be releasable to the general public, including foreign nations.

RL-TR-97-169 has been reviewed and is approved for publication.

APPROVED: *Joseph A. Carozzoni*

JOSEPH A. CAROZZONI
Project Engineer

FOR THE DIRECTOR: *Samuel A. Dinitto*

SAMUEL A. DINITTO, JR., Director
Command, Control & Communications Directorate

If your address has changed or if you wish to be removed from the Rome Laboratory mailing list, or if the addressee is no longer employed by your organization, please notify RL/C3CA, 525 Brooks Rd, Rome, NY 13441-4505. This will assist us in maintaining a current mailing list.

Do not return copies of this report unless contractual obligations or notices on a specific document require that it be returned.

COSMOS – A SYSTEM FOR ACCUMULATING AND MANAGING DISTRIBUTED DESIGN KNOWLEDGE

Contractor: Lockheed Martin
Contract Number: F30602-92-C-0014
Effective Date of Contract: 20 July 1992
Contract Expiration Date: 28 February 96
Program Code Number: 3D30
Short Title of Work: COSMOS
Period of Work Covered: Jul 92 - Feb 96

Principal Investigator: William Mark
       Phone: (415) 354-5236
RL Project Engineer: Joseph Carozzoni
       Phone: (315) 330-7796

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE Oct 97	3. REPORT TYPE AND DATES COVERED Final Jul 92 - Feb 96

4. TITLE AND SUBTITLE
COSMOS - A SYSTEM FOR ACCUMULATING AND MANAGING DISTRIBUTED DESIGN KNOWLEDGE

6. AUTHOR(S)

JON DUKES-SCHLOSSBERG & WILLIAM MARK

5. FUNDING NUMBERS

C   - F30602-92-C-0114
PE - 61101E
PR - H767
TA - 00
WU - 01

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Lockheed Martin Missiles & Space
Advanced Technology Center
3251 Hanover Street
Palo Alto, CA 94304-1191

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Advanced Research Projects Agency   Rome Laboratory/C3CA
3701 North Fairfax Drive   525 Brooks Rd
Arlington, VA 22203-1714   Rome, NY 13441-4505

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

RL-TR-97-169

12b. DISTRIBUTION CODE

N/A

13. ABSTRACT (Maximum 200 words)

This report describes the research performed to demonstrate the implementation of key computational infrastructure technology for managing large-scale design efforts. COSMOS supports the negotiations of designers working on different computer applications in a distributed environment. The negotiations of designers are guided by presenting them with dynamic feedback on the impact of their proposed changes on the existing design. Coordination with all designers impacted by the proposed change is also performed via a context sensitive mechanism. LOOM, the underlying knowledge representation language and active knowledge base used in COSMOS was extended to create and reason about representations of objects in distributed design models. Technology developed includes software mediators, software wrappers, and autonomous software agents.

14. SUBJECT TERMS

Software, Knowledge-based systems

15. NUMBER OF PAGES
24

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

1 Objective

This three year effort has demonstrated the implementation of key computational infrastructure technology for managing large scale design efforts. Cosmos supports the negotiations of designers working on different computer tools in a distributed environment, guiding their negotiations by presenting them with dynamic feedback on the impact of their proposed design changes. Loom, the underlying knowledge representation language used in Cosmos, has been extended to create and reason about representations of objects in distributed design models. Two closely related efforts were funded extensions to Cosmos:

- Genie - develop autonomous software agents that facilitate user access to distributed remote terrestrial sensing (RTS) data and processing services connected via Cosmos infrastructure technology; and

- IWSDB - apply some of the Cosmos infrastructure technologies towards flexible and dynamic information access for the Integrated Weapons System Database (IWSDB) Phase 6 project.

2 The Cosmos Story

Cosmos extends Lockheed Martin-developed commitment-based reasoning [Mark et al. 92] to the distributed design environment. Commitments are the subset of design constraints that determine whether a particular component fits into a particular design. Lockheed Martin's Comet system demonstrated that commitment management is viable for acquiring and organizing design knowledge for single designer interaction. Cosmos is the next step, designed to show that commitment management is a viable method for dynamically acquiring and distributing the shared knowledge required to support design negotiation at human interaction performance levels.

A key element of Cosmos is its use of the Loom system [MacGregor 91]. Cosmos derives significant leverage from its use of Loom's term definition facility and its description classifier -- a specialized inference engine designed to reason with definitions and other descriptive knowledge. Extensions are underway to support Cosmos reasoning including a modular context mechanism and concurrent access to a shared Loom server.

A major goal of the Cosmos project is to interact with other ARPA-sponsored distributed knowledge sharing projects to provide a testbed, to add value to their efforts, and to build upon their work. Specifically, Cosmos is interacting with SHADE personnel in the development of an ontology in the Cosmos domain and in the use of the KIF and KQML knowledge interchange languages. Cosmos is also interacting with the internal Lockheed Martin research project Knowledge-Centered Design to leverage their work in wrapper technology. In turn, Cosmos is stressing these technologies, providing feedback to their developers, and providing a distributed design environment in which to experiment with their software products. Figure 1 illustrates the Cosmos architecture.
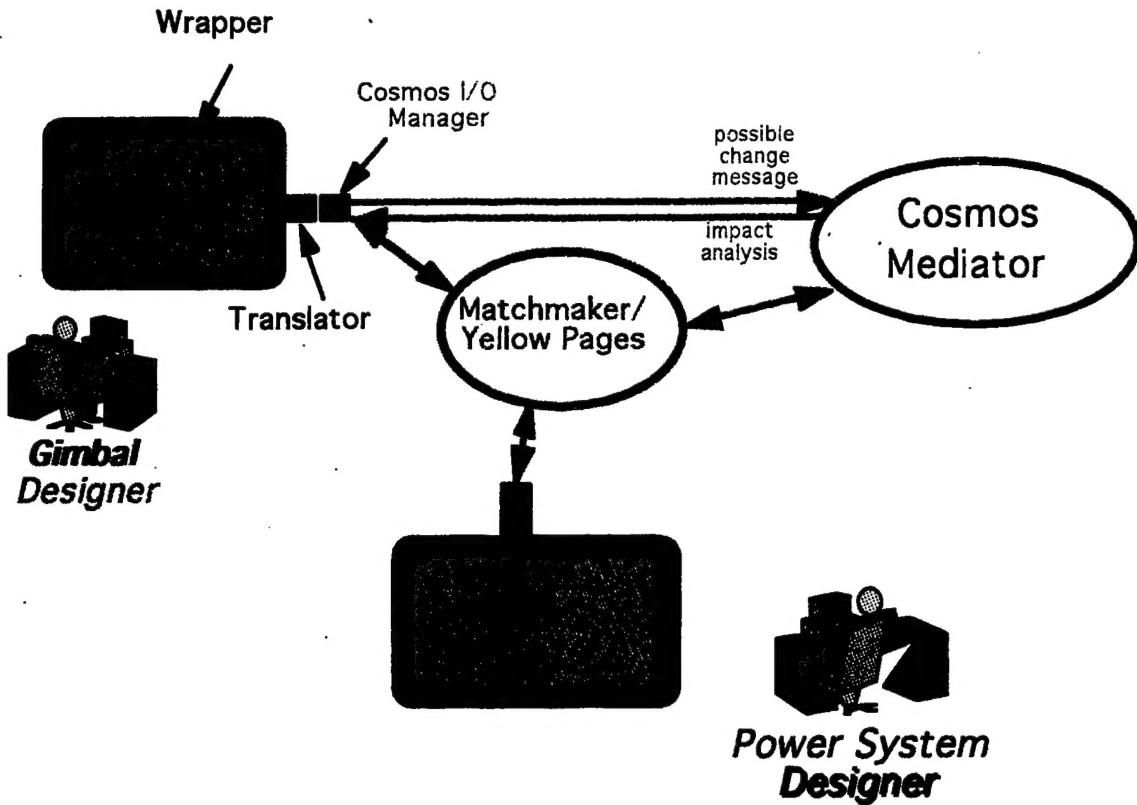
Figure 1. The Cosmos architecture is composed of the Cosmos mediator (red), SHADE communication and facilitation agents (blue), and Lockheed Martin-designed wrappers (green) around the I-DEAS commercial solid modeling and analysis tool.

Cosmos developed a usage scenario that integrates Knowledge Centered Design wrapper technology, SHADE routing technology, DICE-5 engineering collaboration technology, with Cosmos reasoning and visualization support. Notably, Cosmos researchers have cooperated with SHADE ontology theorists to develop the satellite ontology and integrated existing SHADE ontologies. This scenario exercises each of these components and not only produces an effective demonstration but has led to design modifications of the component technologies. Figures 2 and 3 present the Cosmos demonstration scenario.

At start-up of the various tools, messages are sent to the matchmaker identifying the various agents, their interests, and their capabilities. For instance the local I/O Managers ask the matchmaker for the address of the Cosmos mediator while the Cosmos mediator informs the matchmaker of its address and capabilities. The matchmaker notifies the I/O Managers of the Cosmos information. Thereafter, I/O Managers communicate directly with the Cosmos mediator.

In the scenario, the gimbal designer receives an engineering change that the payload weight of the spacecraft is increasing. The gimbal designer determines that a larger bearing is necessary. He uses Cosmos to receive impact analysis information on two alternate bearings. After finding one bearing significantly "better" (meets his criteria and causes much less of an impact to other designers), he decides to forward the information to other affected designers to solicit their opinion. Before he does this he annotates the impact analysis information with details of why he is changing the gimbal. Finally, the affected

3

designer (in this case only one) would respond to the first designer with his comments on the proposed change.

Step 1: Designer experiments with a design change

I-DEAS — possible change → Cosmos Mediator
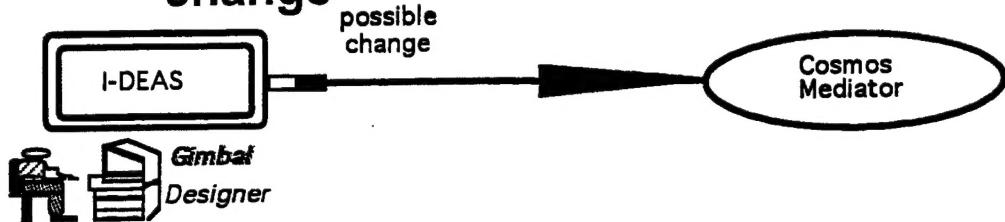
Gimbal Designer

The gimbal designer uses I-DEAS to make a design change and asks Cosmos to provide an impact analysis.

Step 2: Cosmos provides scope of impact

I-DEAS ← Cosmos Mediator

impact analysis
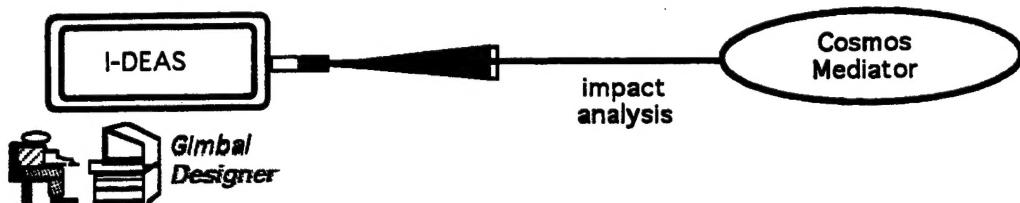
Gimbal Designer

Cosmos provides the scope of impact of the possible change to the gimbal designer, who decides to try a different alternative.

Step 3: Designer tries again

I-DEAS — possible change → Cosmos Mediator

impact analysis
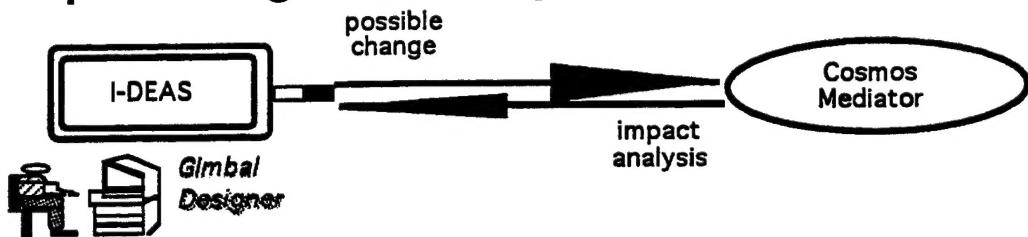
Gimbal Designer

Gimbal designer tries the alternative and receives the new scope of impact.

Figure 2. Cosmos demonstration scenario.

Step 4: Designer actually proposes change
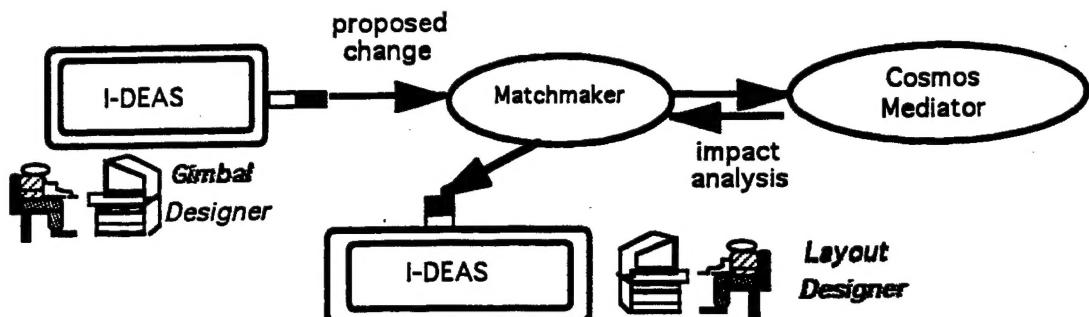
The gimbal designer is satisfied that the second alternative is a viable option, and actually proposes it. Cosmos and the matchmaker provide scope of impact to all stakeholders.

Step 5: Change is *conditionally* accepted
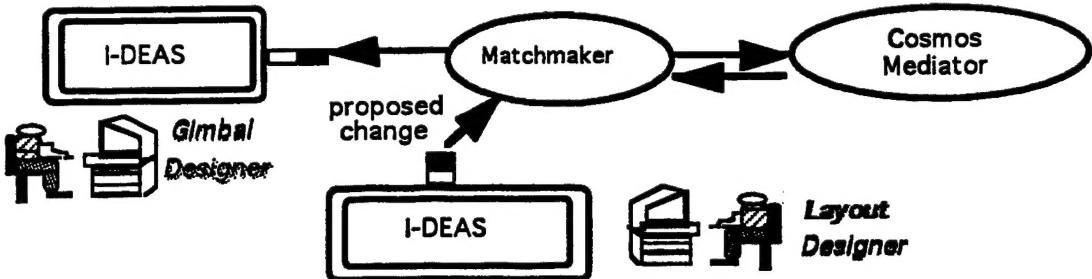
The layout designer examines the proposed change via the scope of impact and proposes a change in his part of the design that would be required to accomodate the proposed change. Cosmos and the matchmaker inform all stakeholders of the now linked change proposals.

**Figure 3**. Cosmos demonstration scenario (cont'd).
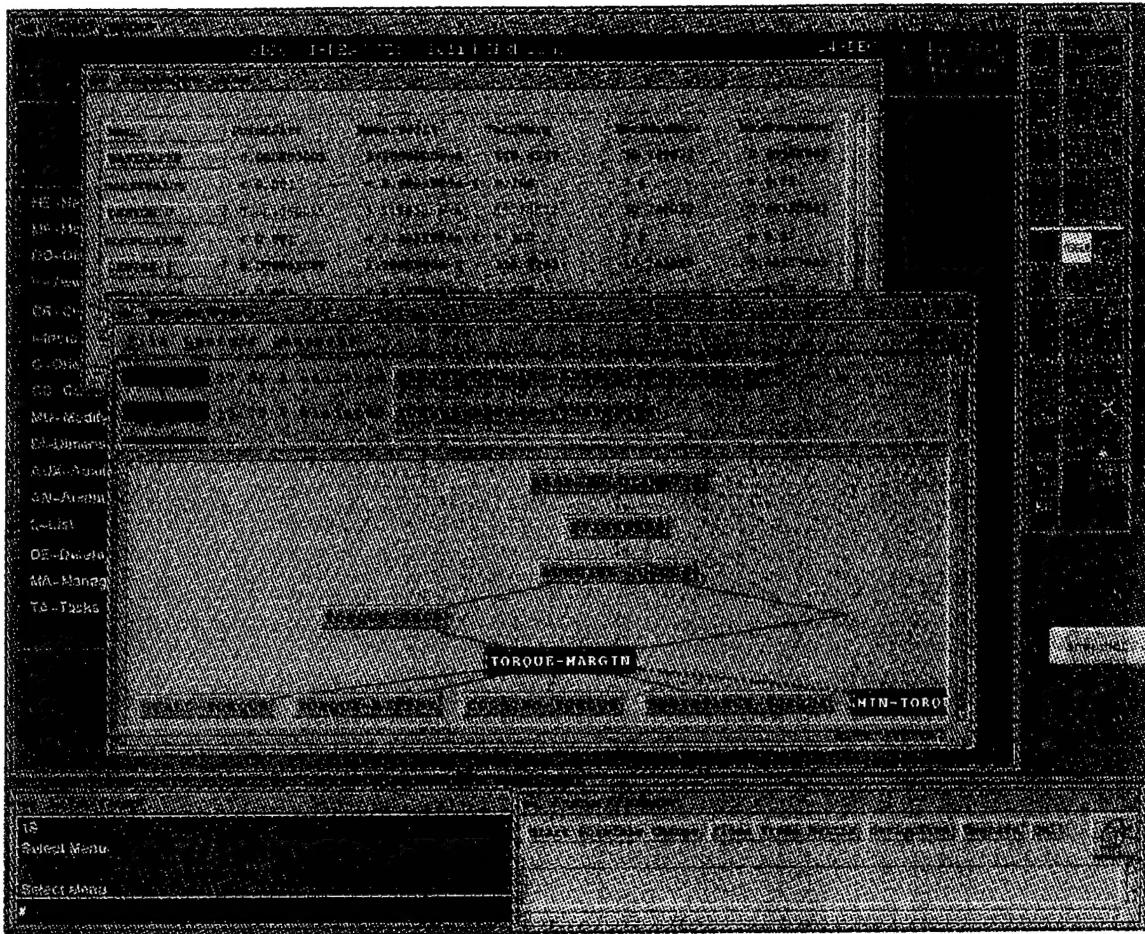
Figure 4. An example screen picture of the Cosmos year III system.

An example screen picture is shown in Figure 4. In the background is the I-DEAS tool, which satellite designers at Lockheed Martin standardly use. In the top foreground is the Cosmos trade-off matrix showing several proposed changes along with commitment values for each change. In the middle is a window associated with one proposed change; it shows a list of violated design constraints at the top and one of these constraints' scope of impact at the bottom.

3 Year III Progress

Year III Cosmos progress centered around:

- scaling the Cosmos satellite design ontology to include more concepts, more commitments, and a new satellite design perspective;

- enhancing the user visualization to incorporate feedback from Cosmos' satellite design consultants; and

- redesigning the existing SHADE matchmaker to use the Loom classifier.

Ontology Progress

The year II Cosmos ontology was written in Loom and contained about twenty commitments, all from the gimbal designer's perspective. A commitment is a constraint of special significance to a certain designer [Mark and Dukes-Schlossberg 94]. During year III, we again worked with two Lockheed Martin satellite designers, Stu Loewenthal and Mike Zinn, to extract more gimbal design commitments as well as to assist us with another satellite designers' perspective. That other perspective we chose was the power designer. The total size of the year III ontology is now approximately 200 concepts and 50 commitments.

An example of a commitment from the power designer's perspective is **max-output-power-constraint**. This constraint is dependent on the type and power requirements of the payload and the type of solar arrays on the satellite and their area and efficiency. Our satellite design consultants determined approximate equations and calculated how a change in one or more of these "input" variables would affect the **max-output-power-constraint**.

For reasoning with this knowledge base, we continued to use Loom's "reasoning with definitions" component. This component allows us the flexibility to write stand-alone commitments, i.e., the designer thinks about and writes a constraint and this translates into one concept in Loom. An assertion that changes a base fact (or facts) in Loom causes an automatic recalculation of all concepts that depend upon this fact. The knowledge base developer writes concepts; Loom elegantly calculates and reasons with the dependencies.

Visualization Progress

The year II user visualization was a significant improvement over the year I interface. driven by our satellite design consultants. Just as much spirited discussion and redesign occurred in year III. The satellite designers, Mike and Stu, had never considered what impact analysis information might look like, how they would use it, and certainly not how they might want it organized on the screen.

Specific visualization extensions incorporated in the year III system include a redesign of the basic scope of impact presentation along with the ability to display and manipulate a summary or trade-off matrix. The theory of design embodied in Cosmos asserts that a designer would pose several alternate redesign scenarios to Cosmos, soliciting feedback how each proposed change affects the rest of the design. After more than two or three alternatives have been posed and Cosmos has responded, it would be hard for the designer to compare alternatives adequately.

The trade-off matrix initially presents all alternatives as the rows and all constraints as the columns in a matrix. The designer can then tailor this presentation to show only certain constraints or certain alternatives. Color is used (sparingly) to indicate constraint violations to provide a quick summary comparison of the alternatives. Our designers believe that users would rely mostly on this presentation and only look to the specific scopes of impact for detailed information.

An important companion visualization to the trade-off matrix is the alternatives history presentation. This depicts a hierarchical view of how design changes are related. For instance, if we assume that the designer needs to redesign the gimbal, he might first choose to consider alternate bearings. Given new bearings, he might then need to replace the

housing, wire harness, and motor. An example presentation from Cosmos is presented in Figure 4.

Matchmaking

In conjunction with the Cosmos subcontractor, USC/ISI, we redesigned the existing Cosmos matchmaker that was originally received from the SHADE project [Kuokka et al. 95]. Key motivations for this work were based on the need to be to do much more sophisticated "matching" and the need to move the matchmaker into a more standard knowledge sharing language.

An example of a match that the new matchmaker can process but the old one cannot is:

- an advertisement states that a certain database knows about all parts in the gimbal, and
- a query is asking about a certain part XYZ (that is in the gimbal).

Given the old matchmaker, this match would fail. The only way it could succeed would be if the database advertised each part in the gimbal separately. The new matchmaker uses a Loom hierarchy to notice that part XYZ is a part of the gimbal and the match succeeds.

The initial implementation of the new Loom-based matchmaker does not implement full matching on the KQML [Finin, MacGregor, and Mark 92] content slot. This was considered beyond the scope of existing technology. Instead, a "service" slot was introduced that captures the essential elements of the content and provides a tractable basis for reasoning.

4   Overall Cosmos Contributions

Cosmos has made several key contributions to the Intelligent Integration of Information (I3) ARPA knowledge sharing community. First and most important, Cosmos implemented a mediator [Wiederhold 92]. At the time of its first development and somewhat still today, solid mediation examples are not common. The Cosmos impact analysis mediator accepts proposed design changes, and, using a formal model of design component interrelations, manipulates the input information to produce a scope of impact analysis. This manipulation of information, rather than syntactic translation or routing, qualifies Cosmos as a mediator. As one of the first (1993) mediator implementations, Cosmos broke new ground in the I3 community.

A second key contribution to I3 was the scope of the Cosmos demonstration systems. Since year I, demonstrations have consisted of not only the Cosmos mediator but also ontologies, wrappers. facilitators, and agent communication languages. The original intention of Cosmos was to focus on the design and implementation of the Cosmos mediator; however due to the "early" start of Cosmos, some of these components had to be implemented by the Cosmos team. Specifically, no ontology for engineering was in place (in 1992) so it became an objective of Cosmos to design and build an ontology. Luckily we were able to interact significantly with SHADE ontology theorists Tom Gruber and Dan Kuokka. and to use their evolving ontologies as they became available.

Regarding wrappers, we did succeed in using a SHADE-developed wrapper for the I-DEAS commercial solid modeling and analysis tool.[3] For matchmaking, we initially used the SHADE-developed matchmaker and for two years this suited our needs well. For agent communication languages, we initially used the Knowledge Interchange Format (KIF) [Genesereth and Fikes 92] language for content and then later switched to Loom. We used KQML for the agent "discourse-level" language. Throughout Cosmos, we kept up with the latest developments of these languages and their application programmer's interfaces, integrating them as appropriate. This system level I3 research, i.e., understanding not only an I3 component, but also how that component fits in and interacts with other essential components was groundbreaking at the time and still important.

A third contribution to the I3 community was pushing the state-of-the-art in ontology development. While I3 ontology theorists were laying the foundations of a solid ontology framework, Cosmos researchers had to build an ontology for immediate use. What ensued was a tight feedback loop between our need for an engineering-level ontology and SHADE's ontology theorizing. Cosmos got a "better" ontology; SHADE was pushed to consider the entire ontology spectrum earlier and thus helped SHADE to produce a better framework.

A final contribution from Cosmos was the ability of our concepts (and thus I3 concepts) to scale. Cosmos year I implementation was modest by comparison to year III yet the ideas carried forward. Loom's reasoning with definitions component handled well the increase in concepts. The expanding visualization, while rethought and redesigned each year, was essentially unchanged from the earliest Cosmos scope of impact research.

Although Cosmos has not been fielded and subjected to the "real" test, we are confident that the ideas are sound and will scale. It is an open question regarding how big the Cosmos knowledge base would have to be to withstand actual designer use; our intuition is the concepts would be in the hundreds, probably not more.

5 NASA-Sponsored Research in Autonomous Software Agents

A related effort to the Cosmos knowledge sharing work has been a project investigating autonomous software agents using many of the Cosmos infrastructure technologies. This work was begun during the second year of Cosmos and made significant progress working with NASA space scientists to understand their problem and propose an autonomous software agents-based solution. This solution centers around providing easy access to NASA-collected data to space scientists around the world.

Remote terrestrial sensing (RTS) data is constantly being collected from a variety of space-based and earth-based sensors. The collected data, and especially "value-added" analyses of the data, is finding growing application for commercial, government, and scientific purposes. The scale of this data collection and analysis is truly enormous, e.g., by 1995, the amount of data available in just one sector, NASA space science, will reach 5 petabytes. Moreover, the amount of data, and the value of analyzing the data, are expected to increase dramatically as new satellites and sensors become available (e.g.,

---

[3] An unfortunate downside to this use of another project's tool was that as the I-DEAS software evolved over the Cosmos project the wrapper did not. This locked us in to the old I-DEAS system and, by year III of Cosmos, we could not even recompile the wrapper because software was so far out of date!

NASA's Earth Observing System satellites). Lockheed Martin and other companies are beginning to provide data and analysis commercially.

Under funding from NASA's technology commercialization program, we have built a "showcase" agent-based RTS data dissemination environment to prove the value of this technology in a real world environment. We have worked closely with personnel from Lockheed Martin's Space Systems Division and Space Imaging Incorporated subsidiary to ground our effort in reality. The key technologies we have used in this effort are:

- explicit representation of software capabilities and execution events relevant to multimedia access and analysis;

- knowledge interchange technology to support the sharing of goals and results among agents;

- reactive planning technology to enable agents to change their behavior in response to changes in the environment; and

- user interface technology to facilitate the specification of agent tasks by a variety of end users.

This work culminated in a demonstration in December 1994 to funding agents. The presentation illustrated users interacting with software agents to access NASA weather and other image data. Figure 5 presents the architecture used for the agent-based customer service center.
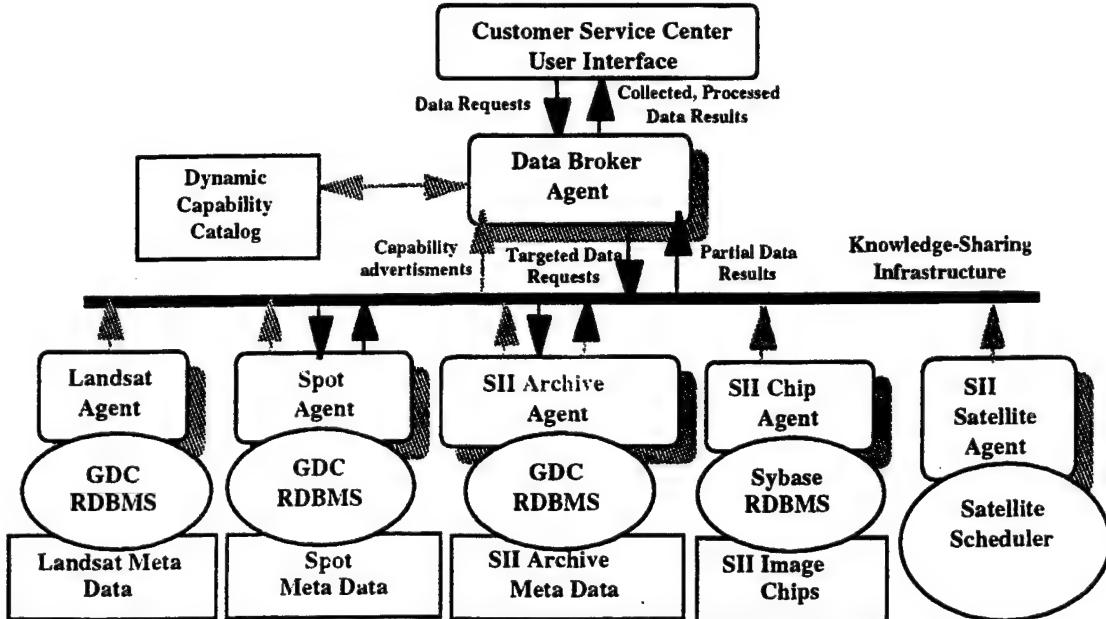

Figure 5. The agent-based customer service center architecture.

AutoClass

Closely related to the autonomous software agents work with NASA has been our work with the AutoClass. A key component of a system that must handle large amounts of data is the ability to provide analysis tools that can assimilate. classify and enhance the user's

understanding of the volumes of data. AutoClass is a non-incremental conceptual clustering algorithm, developed over the last six years by researchers at NASA Ames Research Center. The input to AutoClass is a set of unclassified instances and the output is a probabilistic assignment of the instances to classes using Bayesian methodologies.

Over the last six years, AutoClass has proved itself to be a very robust and useful aid to unsupervised learning. It has been used on the InfraRed Astronomical Spectra (IRAS) data where it has motivated a completely different categorization of stars. It is heavily used by researchers at JPL.

Specific progress on AutoClass has centered around redesigning and reimplementing the system based on requirements obtained from selected users at the NASA Jet Propulsion Laboratory and the NASA Ames Research Center. AutoClass was also converted from LISP to C/C++.

Specific progress on AutoClass has included:

- implemented Single Normal Model,
- implemented Single Log-Normal Model,
- implemented MultiNomial Model,
- implemented ability to handle missing values,
- parallelized Macro level Search on workstation cluster,
- wrote detailed document specifying mathematics and implementation details, and
- achieved 2 orders of magnitude speedup over previous best implementation.

6 ARPA-Sponsored Research for IWSDB

The Integrated Weapons System Database (IWSDB) is a cooperative effort among the Lockheed Martin Aeronautical Systems Advanced Technology Group, the ISX Corporation, and the Lockheed Martin Artificial Intelligence Center. IWSDB has been underway for several years; the AI Center was brought into Phase 6 of the project in 1995 to provide some additional Intelligent Integration of Information (I3) expertise.

The goal of the IWSDB work has been to provide USAF F-22 design engineers with better access to design information. Previous work has centered around bringing text search utilities to the engineer's desktop using hardware already on their desks. Significant information access gains have already been reported (45-70% improvement).

For 1995, project emphasis has been on bringing I3 technology to bear on the IWSDB information access problem. Specifically, facilitators, mediators, wrappers, ontologies, and language issues from AI Center research projects, ISX research projects, and throughout the I3 program have been deployed. Figure 6 depicts the IWSDB Phase 6 architecture.

IWSDB Concept

Designer's Information Desk	Information Integration Services	Data Sources

Query Tool
Info Subscription/ Notification Tool
Schedule Visualization
Document Visualization
Other Data Visualization

MatchMaker
Semantic Translation
Query Interface
Wrappers
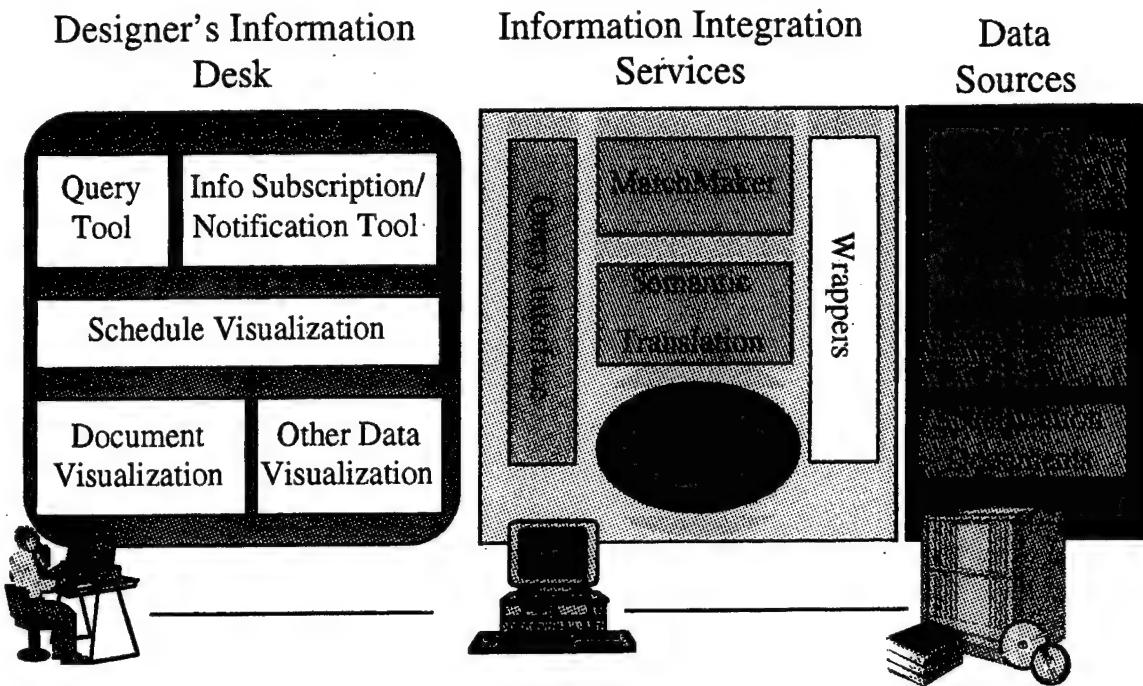
Figure 6. The IWSDB Phase 6 architecture.

For the project, the AI Center is chiefly responsible for building the "middleware" or query management. This query management software accepts queries from the interface in MQL (Mediator Query Language), accepts advertisements or descriptions of capabilities from the data sources, and then routes queries to the appropriate data sources. This routing can be simplistic if a given query directly matches a data source advertisement. Otherwise complex query decomposition may be required if the specified query requires "joining" data from multiple sources. The query manager currently can decompose a query into two or more queries for different sources, route those queries, and then compose the results appropriately.

Another key IWSDB element AI Center personnel have worked on is advertisement strategies. This was found to be a hole in existing I3 research. From the database side, we have proposed to advertise tables and columns using their corresponding terms from the ontology. This is not a completely general solution as, in some cases, actual values may need to be advertised from a table. Initially we are working with just the column names.

From text sources we are finding an advertisement strategy trickier. Our currently implemented solution centers around advertising field names from a semi-structured text source. To fully address the unstructured text problem, advertisements will likely have to be composed by hand rather than by any automated method. We have looked into using some word-count techniques that would allow us to advertisement the n most frequently occurring words in a document. This may hold some promise but would need to be augmented.

1 2

A third area the AI Center personnel have contributed to is overall agent integration. AI Center personnel have taken a lead role with setting up an agent communication framework on-site at Lockheed Martin Georgia. We have also provided significant assistance with KQML (Knowledge Query and Manipulation Language), an evolving knowledge sharing standard from the I3 program. Finally we have contributed to the ontology design as necessitated by the query manager.

Summary

The IWSDB Phase 6 effort successfully integrated a query interface, an infrastructure query manager, a wrapped Sybase database, and a wrapped semi-structured text source. This system has been demonstrated showing F-22 design engineer information access queries being retrieved from real sources. Many issues have arisen during the year and our continuous domain expert interactions have been critical. We have made significant progress and have a system about to be deployed that is the first medium-scale deployment of ARPA-sponsored I3 technology.

7 Future Work

Opportunities for future work are numerous. The most obvious proposal would be to create a deployable Cosmos mediation-based system. This would involve expansion of the existing knowledge base; full coverage of a narrow area would be a wise course.

A second course of action would be the tighter integration of the Cosmos ontology with other I3-developed ontologies. The goal of this work would be to search for synergism; ontology-based systems that dovetail with the Cosmos approach should benefit from more knowledge.

Another promising area would be to integrate the Cosmos commitments into simulation environments. The commitments, or "rules of thumb" as our designers called them, map a designer's input to his outputs; it would be interesting to investigate how these rules could be applied directly by a Mathematica tool, for instance, rather than by a formal reasoning system such as Cosmos.

REFERENCES

[Finin, MacGregor, and Mark 92] Tim Finin, Bob MacGregor, and Bill Mark. Specification of the KQML Agent Communication Language, Enterprise Integration Technologies Technical Report 92-04, 1992.

[Genesereth and Fikes 92] Mike Genesereth and Richard Fikes. Knowledge Interchange Format Version 3.0 Reference Manual. Computer Science Department, Stanford University, Technical Report Logic-92-1, 1992.

[Kuokka et al. 95] Dan Kuokka, Larry Harada, Jay Weber, Jay Tenenbaum, Tom Gruber, and Greg Olsen. SHADE: Knowledge-Based Technology for the Re-Engineering Problem. Final Report. Lockheed Martin Technical Report. 1995.

[MacGregor 91] Bob MacGregor. "The Evolving Technology of Classification-Based Systems," in Principles of Semantic Networks, edited by J. Sowa. Morgan Kaufmann, 1991.

[Mark et al. 1992] William Mark et al. "Commitment-Based Software Development," IEEE Transactions on Software Engineering, October 1992.

[Mark and Dukes-Schlossberg 94] Bill Mark and Jon Dukes-Schlossberg. "Cosmos: A System for Supporting Engineering Negotiation". *Concurrent Engineering: Research and Applications.* 2: 173-182, 1994.

[Wiederhold 92] Gio Wiederhold. "Mediators in the Architecture of Future Information Systems." *IEEE Computer*, 25:38-49, 1992.

DISTRIBUTION LIST

addresses	number of copies
JOSEPH A CAROZZONI RL/C3CA 525 BROOKS RD ROME NY 13441-4505	1
LOCKHEED MARTIN ADVANCED TECHNOLOGY CENTER 3251 HANOVER ST PALO ALTO CA 94304-1191	1
ROME LABORATORY/SUL TECHNICAL LIBRARY 26 ELECTRONIC PKY ROME NY 13441-4514	1
ATTENTION: DTIC-OCC DEFENSE TECHNICAL INFO CENTER 8725 JOHN J. KINGMAN ROAD, STE 0944 FT. BELVOIR, VA 22060-6218	2
ADVANCED RESEARCH PROJECTS AGENCY 3701 NORTH FAIRFAX DRIVE ARLINGTON VA 22203-1714	1
AFIT ACADEMIC LIBRARY/LDEE 2950 P STREET AREA B, BLDG 642 WRIGHT-PATTERSON AFB OH 45433-7765	1
PHILLIPS LABORATORY PL/TL (LIBRARY) 5 WRIGHT STREET HANSCOM AFB MA 01731-3004	1
OL AL HSC/HRG, BLDG 190 2698 G STREET WPAFB OH 45433-7604	1

MISSION
OF
ROME LABORATORY

Mission. The mission of Rome Laboratory is to advance the science and technologies of command, control, communications and intelligence and to transition them into systems to meet customer needs. To achieve this, Rome Lab:

    a. Conducts vigorous research, development and test programs in all applicable technologies;

    b. Transitions technology to current and future systems to improve operational capability, readiness, and supportability;

    c. Provides a full range of technical support to Air Force Material Command product centers and other Air Force organizations;

    d. Promotes transfer of technology to the private sector;

    e. Maintains leading edge technological expertise in the areas of surveillance, communications, command and control, intelligence, reliability science, electro-magnetic technology, photonics, signal processing, and computational science.

The thrust areas of technical competence include: Surveillance, Communications, Command and Control, Intelligence, Signal Processing, Computer Science and Technology, Electromagnetic Technology, Photonics and Reliability Sciences.